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Materials

Corrosion damage evolution and residual strength of corroded aluminum alloys

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Abstract: The LY12CZ aluminum alloy specimens were corroded under the conditions of different test temperatures and exposure durations. After corrosion exposure, fatigue tests were performed. Scanning electron microscopy and optical microscope analyses on corrosion damage were carried out. The definition of surface corrosion damage ratio was provided to describe the extent of surface corrosion damage. On the basis of the measured data sets of the corrosion damage ratio, the probabilistic model of corrosion damage evolution was built. The corrosion damage decreased the fatigue life by a factor of about 1.25 to 2.38 and the prediction method of residual strength of the corroded structure was presented.

Key words: aluminum alloy; corrosion damage; fatigue; statistical analysis; residual strength

1. Introduction

The LY12CZ aluminum alloy has been frequently used in the manufacture of naval aircraft. However, in the inshore circumstance, the alloy is susceptible to corrosion damage [1]. On account of the cyclic nature of aircraft usage, corrosion damage constitutes the potential fatigue crack nucleation sites [2-3].

The influence of corrosion on the fatigue performance of aluminum structures is of considerable importance in the evaluation of the structural integrity of ageing aircraft [4-5]; however, there is still no general, applicable model available to predict the service life of corroded aluminum structures [6]. An experimental study on the corrosion damage configuration of an LY12CZ aluminum alloy structure is presented in this article. A preliminary analytical model, which has been developed to evaluate the effects of prior corrosion on the fatigue property of the aluminum alloy structure, is proposed.

2. Experiment

The material used in this investigation was the LY12CZ high strength aluminum alloy supplied in a form rolled plate. The composition (wt%) of the alloy is Cu 4.68, Mg 1.65, Mn 0.58, Fe 0.28, Si 0.23, and Al balance. All the specimens were precorroded in the EXCO (exfoliation corrosion) solution prepared according to the ASTM G34-Standard test method [7]. The test temperatures were 20, 40, and 60°C and the prior corrosion durations were 10, 20, and 31 d. After prior corrosion exposure, fatigue tests were performed in laboratory air at room temperature, using a closed loop servohydraulic testing machine, and the cycles-to-failure was recorded. The corroded specimens were subjected to constant amplitude cyclic loading with a maximum tensile stress of 256.4 MPa and a stress ratio of R=0.02 at a frequency of 10 Hz. The post-fracture analysis was performed on the fractured surfaces of the specimens using a scanning electron microscope (SEM) to determine the crack nucleation site and the size and geometry of a crack nucleating corrosion pit. An optical microscope was also used to analyze the density of corrosion pits on the surfaces of the specimens [8].

3. Results and discussion

3.1. Corrosion damage configuration and evolution

SEM fractography analysis was utilized to determine the crack nucleation site. The dominant pit can

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be identified by the cracking pattern surrounding the nucleating pits (the blackest semi-elliptic parts are shown in Fig. 1). It can be found that most of the corrosion pits present a semiellipse shape. In general, there are multiple fatigue cracks for almost every specimen, but most fatigue failures are governed by a dominant pit.

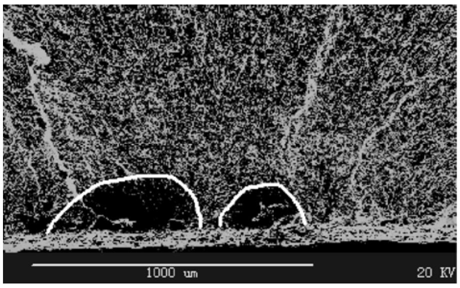

Fig. 1. Fatigue fracture surface showing crack growth from corrosion pits.

An optical microscope was utilized to observe the pit corrosion intensity on the surfaces of the specimens. The surface corrosion damage ratio was used to denote the degree of pit corrosion intensity [9], where it was defined as the percentage of the sum surface area of all corrosion pits to the surface area of the circular corrosion damage region, namely

$$\alpha=\frac{1}{A}\sum_{i=1}^{n}A_{pi}\times 100\% \tag{1}$$

where n is the number of pits, A_{pi} the projective surface area of the ith pit, and A the surface area of the circular region of corrosion damage.

Fig. 2 shows the sketch map of the pit corrosion damage distribution. The measured data sets of the corrosion damage ratio are listed in Tables 1 and 2. Fig. 3 shows the surface corrosion configuration at different corrosion exposure durations.

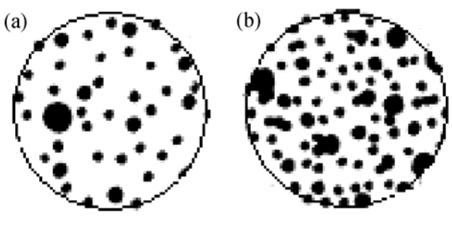

Fig. 2. Corrosion damage ratio: (a) 10%; (b) 20%.

As can be seen in Fig. 3, with the lengthening in corrosion exposure duration, the dimension of corrosion pits becomes larger and small corrosion pits congregate together, and the corrosion damage expands along the specimen surface and cross section directions. At 40°C, when the corrosion durations are 10, 20, and 31 d, respectively, the average corrosion damage ratios are 11.03846%, 13.91231%, and 17.39923%, respectively.

On the basis of the measured data sets of the corrosion damage ratio, nonlinear fittings have been performed to draw the conclusion that the logistic distribution is acceptable for the data sets of the corrosion damage ratio. Figs. 4 and 5 present the cumulative distribution function (CDF) values of the corrosion damage ratio in various corrosive environments.

Table 1. Corrosion damage ratio at different corrosion times (test temperature: 40°C) %

10 d	20 d	31 d
7.23	11.28	14.32
7.41	11.95	15.35
8.3	12.26	15.42
9.39	12.5	15.7
9.39	12.5	16.36
9.61	12.61	16.38
11.12	13.68	16.73
12.38	14.42	16.98
12.38	14.84	17.14
13.55	14.87	19.55
14.03	15.59	19.78
14.27	16.43	20.24
14.44	17.93	22.24

Table 2. Corrosion damage ratio at different temperatures (exposure: 20 d) %

20°C	40°C	60°C
3.8	11.28	19.47
5.37	11.95	20.37
6.64	12.26	20.75
6.97	12.5	21.82
7.27	12.5	22.45
7.57	12.61	22.68
7.82	13.68	27.11
8.46	14.42	31.78
10.86	14.84	—
11.07	14.87	—
11.14	15.59	—
11.19	16.43	—
11.25	17.93	—

The CDF of logistic distribution is shown in the following equation. The parameter values of the logistic distribution are listed in Tables 3 and 4.

$$F(x)=\frac{\exp\left(\dfrac{x-\mu}{\sigma}\right)}{1+\exp\left(\dfrac{x-\mu}{\sigma}\right)} \tag{2}$$

3.2. Damage tolerance analysis of precorroded